

A NOVEL APPROACH TO NATIONAL TECHNOLOGICAL ACCUMULATION AND ABSORPTIVE CAPACITY: AGGREGATING COHEN AND LEVINTHAL

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The paper develops a more precise specification and understanding of the process of national-level knowledge accumulation and absorptive capabilities by applying the reasoning and evidence from the firm-level analysis pioneered by Cohen and Levinthal (1989, 1990). In doing so, we acknowledge that significant cross-border effects due to the role of both inward and outward FDI exist and that assimilation of foreign knowledge is not only confined to catching-up economies but is also carried out by countries at the frontier-sharing phase. We postulate a non-linear relationship between national absorptive capacity and the technological gap, due to the effects of the cumulative nature of the learning process and the increase complexity of external knowledge as the country approaches the technological frontier. We argue that national absorptive capacity and the accumulation of knowledge stock are simultaneously determined. This implies that different phases of technological development require different strategies. During the catching-up phase, knowledge accumulation occurs predominately through the absorption of trade and/or inward FDI-related R&D spillovers. At the pre-frontier-sharing phase onwards, increases in the knowledge base occur largely through independent knowledge creation and actively accessing foreign-located technological spillovers, *inter alia* through outward FDI-related R&D, joint ventures and strategic alliances.

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1 Introduction

A considerable literature has evolved over the past three decades evaluating the potential of laggard ‘economic units’ (be they countries or firms) to catch up and converge with economic units at the frontier. From the perspective of countries, it has been argued that catching-up countries have the potential to grow at a faster rate than leader countries because they can exploit a backlog of existing knowledge developed elsewhere. This potential is regarded as being dependent on, *inter alia*, the existence of endowment of natural resources, an adequate national social capability and technological congruence (Abramovitz 1986).

The concept of social capability, first introduced by Ohkawa and Rosovsky (1973), has generated considerable debate and analysis, because it incorporates a wide variety of issues, including the adequacy of political, financial, educational, and economic systems, all of which influence the country growth rate. Indeed, Abramovitz (1995) distinguished between two classes of elements. One class includes the “basic social attitudes and political institutions”, the other consists of elements that determine the ability of countries to efficiently absorb and internalise knowledge potentially available at the frontier, i.e., from the lead countries. This latter group has been dubbed as ‘absorptive capacity’. Dahlman and Nelson (1995) define national absorptive capacity as “the ability to learn and implement the technologies and associated practices of already developed countries”. However, the nature of national absorptive capabilities has thus far eluded further elaboration, partly due to analytical difficulties of defining absorptive capacity on a macro level. Nonetheless, some analysis has been undertaken on the national level (Verspagen 1991, Keller, 1996) although this line of research has tended to approach the issue of technological accumulation with absorptive capacity as a ‘black box’.

Absorptive capacity has been more extensively analysed at the firm level, where technological learning and technological change take place, and where available data have allowed researchers to assess the role of absorptive capacity in the firm’s innovation performance. The seminal work of Cohen and Levinthal (1989, 1990) provides a robust basis on which much of the subsequent industry-level analysis has been undertaken (see e.g. Becker and Peters, 2000).

However, while this body of literature has tried to measure the ability of a firm to integrate and exploit external knowledge, little research has been done to examine the determinants of a country’s absorptive capacity and its relationship with national R&D activities, and the general characteristics of the international technological environment. We believe that understanding how these elements are interconnected is crucial if one wants to analyse the catching-up process and the international diffusion of technology.

Our objective is to develop a clearer and more precise specification and understanding of the process of national-level knowledge accumulation and absorptive capabilities by applying the reasoning and evidence from the firm-level analysis pioneered by Cohen and Levinthal. In other words, we intend to address the dynamics of national knowledge accumulation by approaching the problem by aggregating from a micro-, firm-level basis. In doing so, we acknowledge that there are important synergistic effects that come into play at a national level, due not only to inter-firm and inter-industry influences, but also due to systemic and institutional elements that facilitate absorption. Furthermore, significant cross-border effects due to the role of both inward and outward FDI exist. Much of the extant literature on the macro-level has concentrated on the influence of trade, despite the growing significance of cross-border investments by multinational enterprises, who increasingly undertake R&D activities outside their home location.

We specify a non-linear relationship between the ability of a country to absorb foreign knowledge and its stage of technological development to try and capture the cumulativeness property of this learning process and the increase complexity of external knowledge as the country approaches the technological frontier. We distinguish between four stages of knowledge accumulation: the pre-catching up stage, the catching-up stage, the pre-frontier-sharing stage, and the frontier-sharing stage. This paper concentrates on understanding and distinguishing between the dynamics of the catching-up and the pre-frontier sharing stage, seeking to explain why the rapidity of technological accumulation associated with catching-up is not usually sustained at the same level as countries approach (but are not as yet *at*) the technological frontier. Absorptive capacity supports further accumulation of technological knowledge, and technological advances support the further development of absorptive capacity in a cumulative, interactive and virtuous process during the catching-up stage. However, this virtuous circle of technological accumulation takes place only if an “adequate” minimum level of absorptive capacity is initially present. Acquiring and sustaining this threshold level of absorptive capacity occurs in the ‘pre-catching-up’ stage. As the country approaches the technological frontier¹, the accumulation process proceeds at a slower pace (‘the pre-frontier-sharing’ stage). The assimilation of external knowledge becomes more difficult, both because of the complexity and the quantity of knowledge than can be acquired. The main theoretical implication of such formulation is that national absorptive capacity and the accumulation of knowledge stock are simultaneously determined and that absorptive capacity is not constant along the convergent path: it evolves with the country’s

¹ We define the technological frontier as the set of all production methods which at any given time are either most economical or most productive in the world.

technological development.² Countries at different stages of development will have different abilities to assimilate technological spillovers. This subsequently means that technological accumulation in the catching-up phase requires absorption of trade and inward FDI related spillovers, while closer to the frontier, innovation through non-imitative means and outward FDI play a more significant role. In the subsequent analysis we will focus on the case of ‘catching-up’ and ‘pre-frontier-sharing’ stage countries, assuming that they have passed the minimum threshold level of absorptive capacity.

The paper is organised as follows. In the next section we provide the theoretical background for our study, introducing the various caveats that need to be acknowledged in the aggregation of absorptive capacity and knowledge accumulation from the firm level approach of Cohen and Levinthal (1989). Based on this theoretical reasoning, sections 3 and 4 develop a formal model of the analytical framework. Finally section 5 summarises the main conclusions and implications of our analysis.

2. Theoretical background

Clarifying the definition of absorptive capacity

Our definition of national absorptive capacity is derived from the firm-level analysis contained in the seminal paper by Cohen and Levinthal (1989). Cohen and Levinthal define absorptive capacity as “the fraction of knowledge in the public domain that the firm is able to assimilate and exploit”. It represents the link between the firm’s in-house capabilities in developing and improving new products on the one hand, and the external stock of technological opportunities on the other. Absorptive capacity therefore determines a firm’s ability to incrementally increase its technological knowledge stock through the adaptation and application of outside knowledge sources.

It is important to note that Cohen and Levinthal’s conceptualisation is based around the notion that absorptive capacity declines as the firm approaches the frontier. Strictly speaking, their interpretation measures the *ability to absorb* available knowledge. The stock of knowledge is taken to be finite (i.e., the frontier in any given sector is fixed) and thus the stock of knowledge must naturally decline as firms approach the fixed frontier. In addition, because external knowledge becomes more difficult to assimilate, the firm can increase absorptive capacity only if increases its R&D efforts. This implies that there are diminishing returns on marginal increases in absorptive capacity at the upper

² As Verspagen (1997) has pointed out, this aspect seems to have been disregarded in empirical analysis of international technological spillovers, e.g., Coe and Helpman (1995). Although Coe and Helpman examined this issue for a sample of industrialised countries, the inclusion of catching-up economies (such as Israel, Spain, Ireland, Portugal, and Greece), and the period covered (from 1971 to 1990) means that omitting differences in national absorptive capacity limits the inferences one can draw.

extreme, i.e., the frontier-sharing stage. This conceptualisation is fundamentally different from the *capability to absorb*, which continually increases. The *capability to absorb* reaches its maximum value at the frontier, even though (theoretically) there is nothing to absorb.

In developing an understanding of national absorptive capacity, it is worth noting that the concept of national absorptive capacity has so far been associated in the international technology transfer literature with the concept of national technological capabilities, and in the endogenous growth literature with the concept of human capital (Lucas 1988, and Romer 1990). Before proceeding further with our analysis, it is useful to clarify the differences between these notions.

Fransman (1984, p.10) defines technological capabilities those used in,

“The search for available alternative technologies and the selection of the most appropriate technology; the mastering of technology, that is its successful use in the transforming of inputs into outputs; the adaptation of the technology in order to specific production condition; the further development of the technology as the result of minor innovations; the institutionalised search for more important innovations with the development of R&D facilities; the conducting of basic research”.

Within this definition, technological capabilities include not only the ability to search and select the most appropriate technology to be assimilated from existing ones available- absorptive capacity- but also the creation of new knowledge through investment in R&D. Thus, absorptive capacity represents a subset of technological capabilities, although disentangling them is not an easy task because these two endeavours tend to share similar resources. Both capabilities are determined by R&D efforts and contribute to the technological upgrading of a country, although their relative importance changes along the convergent path.³ However, absorptive capacity, although determined in part by the country R&D efforts, also reflects the ability of a country to integrate its existing and exploitable resources – technological opportunities – into the production chain, and the foresight to anticipate potential and relevant technological trajectories available to other economic actors. This ability is therefore affected by the international technological situation more than other elements of technological capabilities, and determines a country’s technological dynamism.

Much of the extant work at both the macro-level and micro-level correctly considers it axiomatic that the primary determinant behind technological accumulation and absorptive capacity is human capital. Indeed, the definition of human capital shares some commonality with the concept of absorptive capacity and several empirical studies have in fact used human capital measures as proxies for absorptive capacity (see for example Verspagen, 1991 and Borenzstein *et al.*, 1998). Both human

³ In the pre-catching up phase and in the early stages of the catching up process, R&D is more likely to provide support to firm’s production and operations related to the imitation activity, than to involve long-run pioneering development work in new products and processes.

capital and absorptive capacity involve learning activities and therefore are cumulative processes: The competence “...to evaluate and utilize outside knowledge is largely a function of the level of prior related knowledge” (Cohen and Levinthal, 1990: 128). Qualified human resources are essential in monitoring the evolution of external knowledge and in evaluating their relevance, and for the integration of these technologies into productive activities.

The point we are leading up to is that while human capital represents a core aspect of absorptive capacity, its presence *per se* is not a *sine qua non* for knowledge accumulation. Human capital represents a subset of absorptive capabilities. While both physical and human capital are necessary inputs for catching-up, the lack of appropriate incentives for production and investment can compromise the success of the technological upgrading (Lall, 1992). The availability of a large stock of suitably qualified workers does not in itself result in efficient absorption of knowledge, as is well illustrated by the former centrally planned economies of Eastern Europe. This requires the presence of institutions and economic actors within industry which defines the stock of knowledge in a given location, and the efficient use of markets and hierarchies, be they intra-firm, intra-industry or intra-country. This knowledge is not costless, and must be accumulated over time. Important externalities arise which impinge on the ease of diffusion and efficiency of absorption and utilisation of external knowledge.

Absorptive capacity is therefore also concerned with the efficient use of knowledge acquired. Firms need the ability to use prior knowledge in the solution of practical problems that are commercially viable. Thus, absorptive capacity implies problem-solving skills that emerge directly as a result of attempts to assimilate external knowledge. These efforts represent a potential for learning how to undertake different activities through investing in R&D, i.e. to create new knowledge, and is referred to as the process of ‘learning to learn’ (Lundvall, 1992). Absorptive capacity accumulates only if an effort to internalise the external knowledge is exerted and in particular if the prior-knowledge has been applied to the solution of problems.

Caveats to aggregating from the firm-level

Although there are considerable parallels between the firm and national level of analysis of absorptive capacity, a country’s absorptive capacity is not simply an aggregation of its firms or its industries. There are numerous additional, combinatorial and multiplicative effects which – although negligible at the firm-level – take on considerable significance at the national level.

It is worth reiterating that absorptive capacity includes the ability to internalise knowledge created by others and modifying it to fit their own specific applications, processes and routines. Two important assumptions to the Cohen and Levinthal concept should be noted that are significant to our own subsequent discussion. First, *spillovers must exist*. Firms will only be able to exploit other firms’

knowledge to the degree that it has ‘spilled out’. Second, *absorption is not purely about imitation*. Firms cannot absorb outside knowledge unless they invest in their own R&D, because it can be highly specific to the originating firm and be partly tacit in nature. In addition, absorptive capacity is assumed to be a function of firm’s R&D efforts, as well as the degree to which outside knowledge corresponds to the firm’s needs, and the general complexity of external knowledge.

As we pointed out before, national absorptive capacity is influenced by external technological environment. This implies two important issues that need to be incorporated into our approach, which are less significant on the micro-level. First, that firms operate in a milieu associated with a ‘systems of innovation’, which leads to important synergies due to interaction between firms in a given industry and those in other industries. Second, as with firms, countries do not exist in technological isolation. Absorptive capability is therefore affected by the external technological situation, and these may be associated with other firms in other countries. These two points represent a major difference between the macro-level work on knowledge accumulation and the ‘bottom-up’ aggregated approach used in this paper.

We highlight two fundamental aspects of the systems of innovation here. First, there exists a broader non-firm-specific knowledge base within what might best be described as ‘non-firm actors’ that are crucial to a country-level understanding of the process of technological accumulation. Non-firm actors determine the knowledge infrastructure that supplements and supports firm-specific innovation. We define ‘knowledge infrastructure’ in the sense proposed by Smith (1997) as being ‘generic, multi-user and indivisible’ and consisting of public research institutes, universities, organisations for standards, intellectual property protection, etc that enables and promotes science and technology development. They account for a certain portion of the stock of knowledge at the national level which may be regarded as ‘general knowledge’ in the sense that it has characteristics of a public good, and potentially available to all firms that seek to internalise it for rent generation.

Second, there are institutions that determine the interaction between participants of an innovation system. By institutions we mean the ‘sets of common habits, routines, established practises, rules, or laws that regulate the interaction between individuals and groups’ (Edquist and Johnson 1997). Institutions create the milieu within which innovation is undertaken and establishes the ground rules for interaction between the various economic actors, and represents a sort of a ‘culture’ of innovation and therefore influence the dynamics of the learning process (Freeman 1992, Johnson 1992, Narula 2002). Thus, while the stock of general knowledge is potentially available to all firms, firms that are embedded within a given system of innovation have a lower cost of utilising it, than firms from outside the system. It is not only the creation of new knowledge but also the diffusion of extant knowledge which determines the effective national technological knowledge stock and therefore the accumulation of national absorptive capacity. In other words, there are agglomeration

effects that need to be considered in the process of aggregating from a firm-level to the national-level, due in part to the complex interactions within systems of innovation.

The importance of such an institutional framework is well illustrated by the failure of the former centrally planned economies of Central and Eastern Europe to exploit their formidable human capital assets efficiently since transition. Inefficiencies in the allocation of resources, high resistance to innovation within existing firms and institutional and political systemic elements were some of the factors that prevent the realisation of the absorption potential. In essence what has been missing in these countries is the institutional setting within which knowledge and transactions can be organised efficiently (Gomulka, 1990).

Equally important are the cross-borders interactions among national innovation systems arising from the increasing internationalisation of production, through FDI and strategic alliances. The macro-level literature on international R&D spillovers largely tends to concentrate on trade-related spillovers (e.g., Keller 1997, Coe and Helpman 1995, 1997, Verspagen 1997). The micro-level literature has tended to focus on inward FDI-related spillovers (see e.g., Blömstrom 1989, Kokko 1994, Aitken and Harrison, 1999) and does not take a holistic view incorporating knowledge accumulation and absorptive capability. Very few studies have analysed the role of both inward and outward FDI as a channel of technology transfer (Potterlberghe and Lichtenberg, 2001, and Braconier et al. 2002 are notable exceptions).

The growing role of inward FDI, such that foreign owned affiliates often represent a substantial share of production capacity in many catching-up countries (and a substantial share of business expenditures on R&D) suggests that technological capabilities in a given location are not entirely determined by the domestically owned firm sector. Therefore, a distinction needs to be made between domestically-owned and foreign-owned firms in a given location. Countries increasingly rely on inward FDI as an explicit means to improve their technological and economic competitiveness, and this applies to developing and industrialised countries alike.

The growing significance of outward FDI that involve R&D activities (e.g., Dunning and Narula 1995, Patel and Vega, 1999, Serapio and Dalton, 1999, Criscuolo and Narula 2001) represents another effective vehicle for cross-country transfer of technology. MNEs from industrialised and newly industrialised countries undertake a growing share of their R&D activities in foreign locations with the primary motivation to foreign centres of excellence to absorb, monitor and acquire localized technological advances. A recent empirical study by Potterlberghe and Lichtenberg (2001) finds evidence in favour of the idea that outward FDI is indeed used for technology sourcing and it contributes to increasing the home country productivity.

Nonetheless, the extent and nature of both inward and outward FDI varies by the stage of economic development (e.g., Narula 1996, Narula and Dunning 2000). It is axiomatic that domestic

firms from home countries at an early stage of development do not possess sufficient technological advantages to undertake foreign production, much less engage in R&D in foreign locations. In other words, there is a threshold level of accumulated technology necessary before firms possess the appropriate competences to engage in outward FDI, and a higher threshold before they can engage in asset-augmenting R&D activities in foreign locations. This distinction between knowledge accumulation by domestic firms in their home country, affiliates of foreign owned MNEs and domestic MNEs engaged in outward FDI needs to be introduced in the aggregation of the Cohen and Levinthal model.

The international element is likewise important in determining the country's ability to absorb, i.e. the distance to the technological frontier. At one extreme, countries lagging too far behind are not able to efficiently interpret and internalise technology, whether its source is trade-related or FDI-related. The existence of threshold level effects has been reported in empirical analysis on FDI and trade related R&D spillovers. Studies by Borzenstein *et al.* (1998) and Xi (2000) on the effects of foreign direct investment on host-country economic growth have found that FDI has a positive impact on per-capita income growth only in those developing countries that have attained a certain minimum level of absorptive capacity. Romer (1993) and Cohen *et al.* (1997) report evidence of a similar threshold effect for the ability of a country to benefit from spillovers generated by imports of machinery and equipment.

At the other extreme, near the technological frontier, the country's ability to absorb external knowledge and therefore imitate advanced goods becomes less efficient for a given level of R&D investment. Barro and Sala-i-Martin (1997) in their model of technological diffusion formalise this idea arguing that backward countries can select for imitation only from the uncopied subset of the lead country's technology stock and that the follower will first chose to imitate technologies that are easier and cheaper to imitate. The cost of imitation increases as the follower closes the gap with the leader and the number of technologies to be imitated reduces. That is, the amount of knowledge readily available that the follower country can exploit is smaller, because most of it has already been imitated, and the residue is more complex, having a higher level of tacitness. Once a country is near the international best-practice a higher level of uncertainty is involved, and it is complicated to identify what is relevant, how to solve problems related to the exploitation of new technology: the task difficulty and the knowledge complexity rapidly increases. At the frontier, technologies are pre-paradigmatic and unproven, and there may be several competing technologies, only a few of which will be adopted, and prove to be commercially viable (Narula 2001). Besides, firms at the technological frontier are unwilling to sell state-of-the-art technologies to potential competitors, at least through arms-length transactions. Firms seeking access often resort to cooperative strategies such as joint ventures and R&D alliances, as markets for nascent and new technologies do not exist (Narula

1999). For similar reasons, it has been argued that the threat of a high potential for imitation by host country firms can influence the technological content of the capital goods imported by multinational affiliates (Glass and Saggi 1998).

This implies that absorptive capacity is not constant along the converging path: it evolves with the level of technological development. Different countries at different distances from the frontier acquire and assimilate technological spillovers using different modalities. During the catching-up phase, absorptive capacity is predominately directed at assimilating spillovers originated from trade and/or inward FDI. This strategy was fundamental to the rapid growth of the Asian newly industrialising economies during the 1970s and 1980s, and countries such as Malaysia and China more recently. At the pre-frontier-sharing phase (as well as at the frontier) increases in the knowledge base occur primarily through an active engagement in accessing to foreign located technological spillovers, through outward FDI-related R&D, joint ventures and strategic alliances. This has been the strategy of the Asian NIEs since the 1990s.

3. National Absorptive Capacity

According to the firm level definition proposed by Cohen and Levinthal (1989) absorptive capacity (γ) is a function of the investment in R&D efforts (m) and complexity and relevance of external knowledge (β). In particular, absorptive capacity increases with the firm's R&D investment but at a decreasing rate and when external knowledge becomes more complex the firm will assimilate less for a constant level of R&D investment. In addition when outside knowledge becomes more difficult to acquire, the firm can increase absorptive capacity only if it increases its R&D efforts. The relationship among these variables can be represented by these concavity conditions⁴:

$$\begin{aligned} \gamma_i &= \gamma(m_i, \beta) \quad \text{with} \quad 0 \leq \gamma \leq 1 \\ \text{where } \gamma_m &> 0 \quad \gamma_{mm} < 0 \quad \gamma_\beta < 0 \quad \gamma_{m\beta} > 0 \end{aligned} \tag{1}$$

Extending this reasoning to the macro-level, similar assumptions can be postulated when we define national absorptive capacity if we interpret β as a measure of the technology gap. However, to extend this relationship to the country level we need to introduce some important qualifications. We consider national absorptive capacity as a function of three factors: the country R&D expenditure

⁴ Where f_x stands for $\frac{\partial f}{\partial x}$.

(M_t), the innovation system context that determines the diffusion of knowledge within the country and across countries (ω_t), and the distance to the technological frontier (G_t):

$$\gamma_t = \gamma(\omega_t, M_t, G_t) \quad \text{with } 0 \leq \gamma \leq 1 \text{ and } \omega_t > 0 \quad (2)$$

The technological gap is defined as $G_t = \ln\left(\frac{\bar{Z}_t}{Z_t}\right)$ where \bar{Z}_t represents the knowledge

stock at the frontier and Z_t the technological level that the country has achieved. The characteristics of the knowledge to be assimilated influence the ease of learning from the environment. The distance of the country from the frontier is assumed to be an indicator of knowledge complexity. As the country narrows the gap with the leader, the assimilation of foreign knowledge becomes more difficult because of both the limited amount of technological advances that can be imitated and the increased complexity and uncertainty connected with this activity.⁵ We can therefore assume that as the country closes the gap with the leader absorptive capacity will decrease for given level of R&D effort and institutional set up ($\gamma_G > 0$).

As in Cohen and Levinthal, national absorptive capacity is determined by R&D investment but this variable is defined in a much broader way to include technological and learning activities non-formal innovative activities that may fall out of the rubric of formal R&D. This is to acknowledge the fact that in the pre-catching up phase little or no formal R&D activity is carried out and most of the efforts are concentrated in learning-by-doing and “learning-to-learn”, human resources development and reverse engineering. Furthermore, as postulated in the previous section - following Cohen and Levinthal’s original formulation - we assume that the contribution of research efforts to the accumulation of absorptive capacity is positive but at a decreasing rate ($\gamma_M > 0$ and $\gamma_{MM} < 0$).

In the process of aggregating from the firm-level to the country-level systemic and institutional aspects have to be considered. Although innovation and learning is a firm-specific process, firms are also embedded in a network of linkages with other firms and non-firm actors within an innovation system, and these interactions determine the dynamics of the learning process. The parameter ω_t incorporates different aspects of the institutional set-up which determine the diffusion of external knowledge and the ability to acquire it. ω_t includes the existence and the efficiency of institutions, the degree of openness and the availability of an educated and specialised labour force

⁵ Gomulka (1971) introduces the idea of the “power of absorption” which is determined by the level of technological development.

able to evaluate and assimilate new technologies. The specific value of this parameter will depend on the country's idiosyncratic social, cultural and political factors at a particular stage of development. An increase in ω_t will augment the ability to assimilate foreign knowledge ($\gamma_\omega > 0$). The importance of technological and social congruence cannot be overemphasised in promoting absorption: As economic and technological characteristics become similar to the one prevailing in the 'lead country', a greater amount of external knowledge can be imitated. Thus, higher degree of congruence between the 'lag' and 'lead' country allows more efficient upgrading of technology through the absorption of spillovers and emulation of production methods. ($\gamma_G < 0$).

However the technology gap in each period is the result of previous R&D investment and efforts in absorbing foreign knowledge: absorptive capacity builds through current as well as past R&D efforts.⁶ The distance to the technological frontier is thus not only an indicator of the complexity of knowledge that as not yet been assimilated, but also of the country past efficiency in exploiting knowledge in the innovation and production system.

Finally, it is reasonable to postulate that when the gap becomes smaller, the assimilation of foreign knowledge will only be possible if there is a concomitant increase in national R&D expenditure ($\gamma_{MG} < 0$) or ($\gamma_{M\omega} < 0$). The complexity of knowledge near the frontier requires greater efforts on the part of national firms, a greater amount of information on the available technology (to reduce the uncertainty connected to the assimilation process) and a knowledge base, which extends beyond the domain of national specialization.

Therefore in our model the relationship between absorptive capacity and the country level of development is non-linear due to the opposite effects that the complexity of external knowledge and the cumulativeness property have on the learning process, and, before absorptive capacity begins to increase at all, countries need to have reached a minimum level of prior-knowledge. This will affect the knowledge accumulation process, which is not only driven by national R&D efforts but also by the assimilation of international spillovers, as the knowledge base is determined by the international technology frontier, and not the local one.

It is important to stress that the Cohen and Levinthal specification is static one, and cannot capture the fact that absorptive capacity and the accumulation of knowledge are simultaneously determined. The country's ability to absorb foreign knowledge depends on the level of technological development and at the same time the process of knowledge accumulation is determined by the capacity to assimilate international spillovers. In other words absorptive capacity (γ) is endogenously determined. It is for this reason that the model being developed here is a system of equations.

⁶ As pointed out by Cohen and Levinthal this aspect cannot be captured in their static model.

The non-linear relationship between the absorption capacity and the technological gap can be illustrated using a particular functional form, based on Caniëls and Verspagen (2001), which represents one of an infinite number of functional forms that satisfy the concavity conditions between this two variables.⁷

$$\gamma_t = M \exp\left(-\left(\frac{G_t}{M} - \omega M\right)^2\right) \quad \text{with } 0 < M < 1 \quad (3)$$

Under this formulation the absorptive capacity parameter reaches a maximum of M when G equals to ωM , as illustrated in figure 1. The absorption parameter rapidly increases once the threshold level of knowledge base has been acquired and reaches a maximum when the country achieves an intermediate level of development ('catching-up' phase), because foreign technology is more technological congruent and easier to integrate into the production process. At this stage the follower country level of technological development is such that can take almost completely advantage of the progress being made by the technological leaders. Industrial upgrading through the absorption of technological spillovers and emulation of methods of production already in use in lead countries can in fact only be achieved if "a developing country aligns its pattern of comparative advantage and its stage of development with the advanced countries" (Ozawa, 1992, p.34). As the country approaches the frontier, absorptive capacity declines both because the knowledge available for assimilation is smaller and the complexity involved in its exploitation is higher.

This formulation also implies that an increase in R&D expenditures (from M to M') leads to a higher maximum level of absorptive capacity which is reached at a earlier stage of the catching up process (figure 1). Changes in other variables associated with ω - such as a shift toward a more open policy regime - will also help the country to reach the maximum level of absorption capacity at a larger distance from the frontier.

As stated before, the relationship between absorptive capacity and knowledge stock is a dynamic one, and the next section introduces the dynamic aspects, as well as developing the concept of knowledge accumulation on a national level, once again proceeding from Cohen and Levinthal as a starting point.

⁷ We analyse the partial derivative of the absorption capacity with respect to the technological gap and thus M and the policy variables are constant.

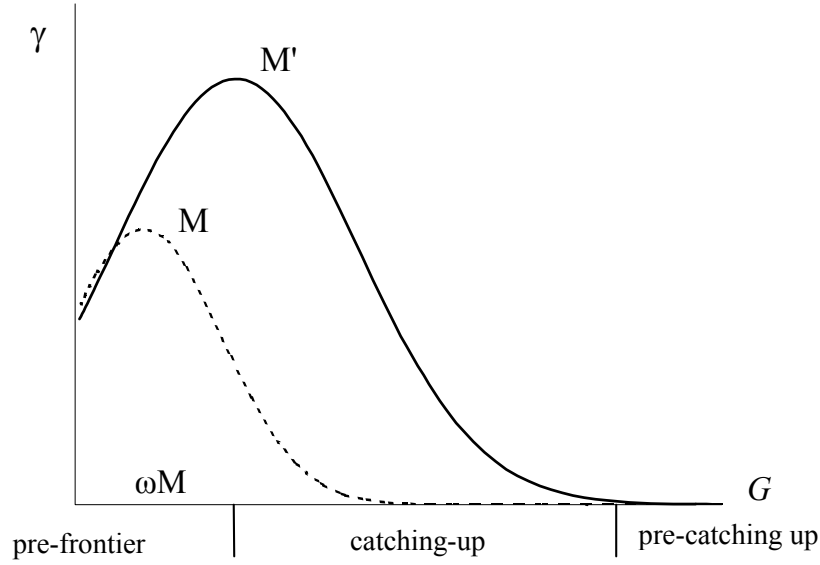


Fig. 1 The non-linear relationship between the absorption capacity and the technological gap

4. The Knowledge Accumulation Process at the Country Level

Cohen and Levinthal (1989) assume that the firm's knowledge flow (\dot{z}_i) is a function of the firm's investment on R&D (m_i) other firm's R&D efforts (m_j), the firm's absorptive capacity (γ_i), the degree of intra-industry spillovers (θ). Furthermore, its knowledge assets involves its being able to capture extra-industry spillovers and general knowledge generated from the research activities of government or university laboratories (T), as formulated in the following equation:

$$\dot{z}_i = m_i + \gamma_i \left(\theta \sum_{j \neq i} m_j + T \right) \quad \text{with } 0 \leq \theta \leq 1 \text{ and } 0 \leq \gamma_i \leq 1 \quad (4)$$

In formalising the aggregation of the Cohen and Levinthal approach, and acknowledging the caveats raised in the previous section, as a first step we rewrite equation (4) to include cumulative technological capacity on a global basis:

$$\dot{z}_i = m_i + \gamma_i^m \theta_m \sum_{j \neq i} m_j + \gamma_i^{\bar{m}} \theta_{\bar{m}} \sum_k \bar{m}_k + \gamma_i^T T \quad (5)$$

$$0 \leq \gamma_i^h \leq 1 \text{ for } h = m, \bar{m}, T \text{ and } 0 \leq \theta_j \leq 1 \text{ for } j = m, \bar{m}$$

The new variable \bar{m} stands for firm-specific R&D investment in the same industry but located in all other countries. T represents 'general knowledge' in the sense that it is associated *inter alia* with (a)

the knowledge infrastructure within the sum total of the individual systems of innovation in all countries; (b) activities of firms operating globally in other industries that result in inter-industry spillovers.

We further introduce different spillovers and absorptive capacity parameters associated with various knowledge sources. We make the reasonable assumption that some technological externalities are more localised: spillovers generated by the R&D activity of national firms are likely to be more intense than the ones originating from the research efforts of firms located in other countries ($\theta_m > \theta_{\bar{m}}$). Furthermore, we assume that the ability to absorb spillovers will be greater if externalities and spillovers available are technologically congruent to the one developed internally by the firm ($\gamma_m > \gamma_{\bar{m}} > \gamma_T$).

We can derive an aggregate formulation of equation (5) under the simplifying assumptions that in the country in question there are n firms, that there are p identical firms located abroad, and there is only one sector in the economy. We can therefore obtain an equation of the accumulation of knowledge at the country level:

$$\dot{Z}_t = \sum_{i=1}^n \dot{z}(t)_i = \sum_{i=1}^n (m(t)_i + \gamma_i^m(t)\theta_m \sum_{i \neq j} m(t)_j + \gamma_i^{\bar{m}}(t)\theta_{\bar{m}} \sum_k^p \bar{m}(t)_k + \gamma_i^T(t)T(t)) \quad (6)$$

To proceed with the aggregation we need to take into account the existence of diversity in the knowledge base among the n national firms. At one extreme all n firms shares exactly the same knowledge; while at the other extreme they each have a completely different knowledge base. If we assume that the firm knowledge base determines the external knowledge that it is able to absorb, we will obtain different aggregated version of equation (6). In the first case each firm will assimilate exactly the same international and extra-industry knowledge spillovers and there will not be any intra-sector spillovers among national firms. In the second case, intra-industry spillovers among national firms are relevant and each firm will be able to absorb different pieces of information from the same external knowledge pool.

If we take the first case, i.e., that each firm has the same knowledge base, we can rewrite equation (6) as:

$$\dot{Z}_t = n\dot{z}_t = nm_t + \gamma_t^{\bar{m}}\theta_{\bar{m}}p\bar{m}_t + \gamma_t^T T_t = M_t + \gamma_t^{\bar{m}}\theta_{\bar{m}}\bar{M}_t + \gamma_t^T T_t \quad (7)$$

Where \bar{M}_t is the amount of R&D expenditures performed abroad and M_t is the total amount of national R&D expenditure, a decision variable that determines the size of the absorptive capacity

parameter. T is the fraction of extra- industry and general foreign knowledge that the n firms in the country are able to assimilate.

If we take the second case, where each firm has a different knowledge base, we obtain:

$$\dot{Z}_t = \sum_{i=1}^n \dot{z}(t)_i = nm(t) + (1-n)m(t)\theta_m \sum_{i=1}^n \gamma_i^m(t) + p\bar{m}(t)\theta_{\bar{m}} \sum_{i=1}^n \gamma_i^{\bar{m}}(t) + T(t) \sum_{i=1}^n \gamma_i^T(t) \quad (8)$$

In between these extreme cases, firms will share some extent of common knowledge base, and therefore they will each exhibit different levels of absorption capacity. However, the formalisation of this more realistic situation would increase the complexity of our analysis.

In order to analyse the role of R&D associated with inward and outward FDI and the contribution of foreign affiliates to the national knowledge accumulation, we distinguish between domestic firms (D) and foreign firms (F). Within both groups of firms, we further distinguish between their location; whether they operate in the country or abroad. We specify two equations for the accumulation of knowledge at the firm-level according to the firm's nationality. We assume that there are n domestic firms and $(1-n)$ foreign firms operating in the country and p foreign firms abroad and $(1-p)$ domestic firms abroad. Foreign and domestic firms carry out R&D activities both in the country (m_D and m_F) and abroad (\bar{m}_D and \bar{m}_F) and the knowledge resulting from these research efforts will spill over to a common knowledge pool. Domestic and foreign firms differ in their absorption capacity of inter-sectoral and international spillovers because they invest different amount of resources in R&D. From equation (5), omitting for simplicity the general knowledge term (T), we obtain:

$$\dot{z}_{Di} = m_{Di} + \gamma_{Di}^{m_D} \theta_{m_D} \sum_{j \neq i}^n m_{Dj} + \gamma_{Di}^{m_F} \theta_{m_F} \sum_y^{1-n} m_{Fy} + \gamma_{Di}^{\bar{m}_D} \theta_{\bar{m}_D} \sum_k^{1-p} \bar{m}_{Dk} + \gamma_{Di}^{\bar{m}_F} \theta_{\bar{m}_F} \sum_h^p \bar{m}_{Fh} \quad (9)$$

$$\dot{z}_{Fi} = m_{Fi} + \gamma_{Fi}^{m_D} \theta_{m_D} \sum_{j \neq i}^n m_{Dj} + \gamma_{Fi}^{m_F} \theta_{m_F} \sum_y^{1-n} m_{Fy} + \gamma_{Fi}^{\bar{m}_D} \theta_{\bar{m}_D} \sum_k^{1-p} \bar{m}_{Dk} + \gamma_{Fi}^{\bar{m}_F} \theta_{\bar{m}_F} \sum_h^p \bar{m}_{Fh} \quad (10)$$

$$0 \leq \theta_{ij}, \gamma_{ij} \leq 1 \text{ for } i = m, \bar{m} \text{ and } j = D, F$$

If we maintain the simplifying assumption that domestic and foreign firms operating in the same country share among themselves the same knowledge base and that the national knowledge accumulation process is the result of the learning and innovative efforts of both groups of firms, we obtain:

$$\begin{aligned} \dot{Z}_t = n\dot{z}_D + (1-n)\dot{z}_F = nm_D(1 + \gamma_{Dt}^{m_D} \theta_{m_D}) + (1-n)m_F(1 + \gamma_{Dt}^{m_F} \theta_{m_F}) + \\ + p\bar{m}_F \theta_{\bar{m}_F} (\gamma_{Fi}^{\bar{m}_F} + \gamma_{Di}^{\bar{m}_F}) + (1-p)\bar{m}_D \theta_{\bar{m}_D} (\gamma_{Di}^{\bar{m}_D} + \gamma_{Fi}^{\bar{m}_D}) \end{aligned} \quad (11)$$

$$\dot{Z}_t = M_D(1 + \gamma_{Dt}^{m_D} \theta_{m_D}) + M_F(1 + \gamma_{Dt}^{m_F} \theta_{m_F}) + \bar{M}_F \theta_{\bar{m}_F} (\gamma_{Fi}^{\bar{m}_F} + \gamma_{Di}^{\bar{m}_F}) + \bar{M}_D \theta_{\bar{m}_D} (\gamma_{Di}^{\bar{m}_D} + \gamma_{Fi}^{\bar{m}_D}) \quad (12)$$

Equation 12 allows us to distinguish between four sources from which country-level knowledge accumulation benefits:

- The “effective” domestic R&D investment ($M_D(1 + \gamma_{Ft}^{m_D}\theta_{m_D})$). The overall contribution of domestic firms’ research efforts to the national accumulation of knowledge includes the assimilation of spillovers by foreign affiliates.
- The “effective” inward R&D FDI ($M_F(1 + \gamma_{Dt}^{m_F}\theta_{m_F})$). This term takes into account that at the aggregate level the result of foreign affiliates’ R&D investment is determined also by the degree to which domestic firms are able to absorb technological spillovers originated from these R&D activities.
- The international spillovers generated by the R&D activity of foreign firms and absorbed by domestic and foreign affiliates ($\bar{M}_F\theta_{\bar{m}_F}(\gamma_{Fi}^{\bar{m}_F} + \gamma_{Di}^{\bar{m}_F})$).
- R&D spillovers originating from the research efforts of domestic firms operating abroad ($\bar{M}_D\theta_{\bar{m}_D}(\gamma_{Di}^{\bar{m}_D} + \gamma_{Fi}^{\bar{m}_D})$) to the extent that domestic and foreign affiliates are able to assimilate them.

There will be considerable variation in the relative importance of each source of knowledge depending upon the stage of technological development of the country. In the pre-catching up phase the primary - and possibly the only - contribution to the accumulation of knowledge will come from national research activities which builds up the minimum threshold level of technological competences. During the catching-up phase the assimilation of foreign R&D spillovers will acquire an important role. As shown by the theoretical and empirical literature on international technology transfer (e.g., Reddy and Zhao, 1990, Amsden 1989, Pack 2001), there are various channels through which national firms can assimilate foreign knowledge. Imports of intermediate goods by domestic firms and foreign affiliates and technology licensing are the most significant. But the presence of foreign affiliates is also another vehicle for transferring the results of foreign R&D investment to domestic firms, as pointed out before.

As the country approaches the frontier, all four sources of knowledge will contribute to the national technology base. Although the country will increasingly rely on its own R&D efforts, since there are declining opportunities for imitation. It must therefore actively engage in the exploitation of foreign knowledge sources through outward R&D FDI. At the same time, it will benefit from the assimilation and exploitation of the technological spillovers originated from the innovation activities that foreign affiliates carry out in the country.

The increasing propensity among multinational firms from European countries, Japan and United States to locate their R&D activity outside their home country reflects this strategy in the

acquisition of technological spillovers. While in the catching-up phase the assimilation of spillovers relies on the activities of foreign firms and imports of intermediate goods, in the pre-frontier sharing phase - and sometimes even before this - firms adopt a more active learning strategy so as to gain access to external knowledge which could otherwise never be exploited.

Absorption of foreign knowledge spillovers is not only confined to the catching-up phase, it continues also when countries reach the technological frontier, although through different means. During the catching-up phase the assimilation activity is addressed at acquiring trade and/or FDI related R&D spillovers, while at the frontier sharing phase it aims at increasing the country knowledge base through outward FDI and strategic alliances.

We can calculate a stock of knowledge as:

$$Z_t = \int_0^t \dot{Z} dt \quad \text{where}$$

$$\dot{Z}_t = M_D (1 + \gamma_{Ft}^{m_D} \theta_{m_D}) + M_F (1 + \gamma_{Dt}^{m_F} \theta_{m_F}) + \bar{M}_F \theta_{\bar{m}_F} (\gamma_{Fi}^{\bar{m}_F} + \gamma_{Di}^{\bar{m}_F}) + \bar{M}_D \theta_{\bar{m}_D} (\gamma_{Di}^{\bar{m}_D} + \gamma_{Fi}^{\bar{m}_D})$$

It becomes now clear that the absorption capacity parameter is an endogenous variables of the model if one recalls that γ is a function of the gap which is equals to $\ln\left(\frac{\bar{Z}_t}{Z_t}\right)$.

5. Conclusions

In this paper we have introduced a new perspective on the concept of national absorptive capacity and knowledge accumulation, by aggregating upwards from the firm-level. We have specified a relationship between the ability of a country to absorb foreign knowledge and its stage of technological development, which takes into consideration the increasing complexity of technological knowledge as the country approaches the frontier and the cumulateness property of this learning process.

This study does not aim at providing a complete explanation of the industrialization and development process. This would require a thorough analysis of the different components of output growth. However, we have highlighted the nature of absorptive capacity, and in particular the need to view national absorptive capacity and knowledge accumulation by emphasising the inclusion of a systemic view of the innovation process. We have also acknowledged differences in economic characteristics due not just to changing industrial structure, but also due to differences in ownership and location of production activities. In particular, we have included the cross-border activities of MNEs, and the significance of both outward and inward FDI in generating spillovers, in addition to arms-length acquisitions of technology.

The cross-border flow of knowledge has always been seen as fundamental to firms, and this imperative has increased with growing cross-border competition, and international production. By aggregating from the firm-level, we have highlighted its importance for industrial policy. Domestic economic actors need access to foreign sources of knowledge in a globalising world, although the importance of different knowledge sources varies by the phase of technological development. Furthermore, this study emphasises the complementary nature of foreign and domestic knowledge sources, and the role of inward FDI in proceeding from the pre-catching up phase to the growing significance of outward FDI in the pre-frontier stage.

Once countries achieve a threshold level of absorptive capacity, absorption and catching-up processes occur rapidly, sustained by externalities due to spillovers associated with trade and inward FDI. The rapid growth of the Asian NIEs in the 1970s and 1980s illustrates this well, as well as the more recent cases of Malaysia and China, and the other ‘new’ tigers (see e.g., Lall and Uruta [eds] 2003, Pack 2001, for a discussion).

As they approach the frontier, countries must have the capacity not just to absorb and imitate technological development created by others, but also the ability to generate inventions of their own. This requires technological capabilities that are non-imitative. In other words, learning-by-doing and learning-by-using have decreasing returns as one approaches the frontier, and in-house learning and learning-by-alliances become more efficient options.

The case of Korea (Amsden 1989, Kim 1995, Sachwald 2001) illustrates the evolution of the ability to assimilate R&D spillovers during the catching-up process. Korea relied on technology licensing and imports of capital goods from developed countries in acquiring external knowledge till the 1980s, but this enabled it only to access second-best practice technologies. Korea is at the pre-frontier sharing or frontier-haring phase in several sectors. Its domestic technological capabilities (inter alia deriving from its education system) are however geared towards absorption through imitation rather than in-house learning (see Kim 1995, Suh 2000). In addition, the difficulty of further assimilation connected to the more tacit nature of advanced knowledge and the reluctance of industrialised countries to transfer technology to Korean firms for fear of losing their technological advantage has aggravated this process. There is now an increasing emphasis technological capability building and on reverse technology transfer, that is, through outward FDI by Korean MNEs (Sachwald 2001, Lee 2001).

The formulation of absorptive capacity proposed in this paper has several limitations. The assumption of one-sector economies narrows the scope of our analysis. We are not able to distinguish between intra-industry and inter-industry spillovers within the country, but only between domestic and foreign spillovers. However, countries tend to be specialised in a limited number of sectors, and therefore this assumption should not compromise the conclusions derived from this

specification. Furthermore according to the structural theory of development the industrial development of a country is composed of discrete stages following a hierarchical order and characterised by different factor intensities, i.e. a country will acquire technological maturity only in specific sectors at a time. The knowledge accumulated in this process will then be applied in the technological development in other sectors, which implies that the country does not always have to build up a minimum threshold level of knowledge base for each particular sector.

Our analysis should be seen as tentative, but we believe it provides the basis for more accurately estimating national absorptive capacity, providing a viable basis for empirical studies using firm- and industry-level data. Nonetheless, there remain considerable lacunae which deserve further theoretical and empirical analysis.

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